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Performance-influencing factors in homogeneous groups of top athletes: a cross-sectional study

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ABSTRACT

INGEN SCHENAU, G. J. VAN, J. J. DE KONING, F. C. BAKKER, G. DE GROOT. Performance-influencing factors in homogeneous groups of top athletes: a cross-sectional study. *Med. Sci. Sports Exerc.* Vol. 28, No. 10, pp. 1305–1310, 1996. Sport scientists have identified many factors as prerequisites for a good athletic performance in various sports. It is not clear whether these factors also influence the best performers in the homogeneous groups of top athletes selected for national teams. In this study, this issue is addressed with members of the Dutch National Junior Speed Skating Team. A total of 237 different technical, physiological, anthropometrical, and psychological parameters were collected, including many that correlated with performance in previous studies. High speed film analyses during the National Championships provided the technique parameters. A 30-s sprint test and a 150-s supramaximal test on a cycle ergometer underlie the physiological data, and questionnaires were used to measure personality traits and emotional feelings. Only trunk position and the direction of push-off (push-off angle φ) correlated consistently with skating performance in this group ($r = 0.61–0.73$ and $r = -0.65$ to -0.70, respectively). The small number of meaningful correlations means that sport scientists will have to develop more reliable methods, models, and theories to contribute significantly to knowledge useful to top athletes and their coaches.

SPEED SKATING, TECHNIQUE ANALYSIS, TESTING, EXERCISE PHYSIOLOGY, SPORT PSYCHOLOGY

Scientists have identified many factors that are prerequisites for a good speed skating performance. Elite skaters can be distinguished from skaters at lower performance levels by the following differences in speed skating technique (3,4,13,15,18,19): a more horizontal trunk position, most likely associated with lower air frictional losses at a given velocity; smaller knee angles at the onset of the push-off (mainly due to a more horizontal position of the upper leg) leading to smaller air frictional losses during gliding and a larger range of knee extension; higher maximal angular velocities and a larger translational push-off velocity; a larger angle of the push-off leg with the vertical during the push-off, resulting in a more effective sidewards push-off; and a higher mechanical work per stroke.

The effectiveness of the push-off correlates strongly with skating performance. From an exercise physiological perspective (7,9–11,14), elite skaters can be distinguished from skaters of lower performance level on the basis of their higher $\dot{V}O_{2max}$ and larger peak and mean power output during supramaximal cycle ergometer tests. The significance of $\dot{V}O_{2max}$ and power values were demonstrated in studies that revealed correlation coefficients up to $r = 0.85$ (7,9,10).

The search for performance-influencing factors in speed skating has been based primarily on studies comparing groups with different performance levels or on studies using correlation techniques applied to results obtained among nonhomogeneous groups of athletes (4,7,8,10,19). One might dispute, however, whether such studies have any significance for coaches of the homogeneous groups of athletes who perform at national and international levels (9,17).

The purpose of this study was to determine factors that correlate with performance in a homogeneous group of elite speed skaters and to compare the presence (or absence) of these correlations with performance-influencing factors identified in previous studies that were based on less homogeneous groups of speed skaters.

During an extensive longitudinal (5-yr) study of the development of young talented male and female speed skaters on the Dutch National Teams (22), anthropometrical, physiological, technical, and psychological data were gathered yearly. The data collected during the 1987–1988 and 1988–1989 skating seasons were used in the cross-sectional analysis for this study.

METHODS

Subjects. Subjects were members of the 1987–1988 and 1988–1989 Dutch Junior Speed Skating Teams or former members who had joined the senior teams. They

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TABLE 1. Best seasonal performances (mean and range) of the 10 male and 11 female subjects during the two successive years of the study (I: 1987-88 and II: 1988-89).

	Mean (SD) I	Range I	Mean (SD) II	Range II
Males				
500 m	39.84 (0.71)	39.06–41.10	39.70 (0.59)	39.00–40.60
1500 m	2:00.08 (2.79)	1:56.30–2:03.63	2:00.21 (2.65)	1:56.94–2:03.55
5000 m	7:21.15 (19.00)	6:56.17–7:54.9	7:15.56 (16.30)	6:52.13–7:35.11
Points	123.98 (3.41)	119.71–128.89	123.32 (2.89)	119.21–127.29
Females				
500 m	43.44 (1.10)	41.80–45.73	42.29 (1.11)	40.53–44.36
1500 m	2:14.66 (3.99)	2:10.27–2:23.42	2:14.32 (2.47)	2:08.64–2:17.78
3000 m	4:48.20 (9.48)	4:35.82–5:06.76	4:46.01 (6.00)	4:36.51–4:59.94
Points	136.36 (3.82)	132.25–144.66	135.73 (2.57)	129.50–138.13

included 11 females and 10 males 16–19 yr old. Each subject signed a written consent to participate, and all were familiar with the tests since they had participated in our longitudinal study in previous season(s).

Speed skating performance is measured as the time needed to cover a certain distance. Competition times are converted to points by expressing them as the time needed to cover each 500 m. For instance, a time of 2 min on a 1500-m distance gives 120/(1500/500)= 40.0 points. Lower numbers indicate better performance than higher numbers. Performance over different distances are added together for a total performance in points. For female speed skaters, the total performance is calculated by adding the points for the 500-, 1500-, and 3000-m distances. For male speed skaters, the total performance is calculated by adding the points for the 500-, 1500-, and 5000-m distances. The means and ranges of the best seasonal times at three skating distances and the points realized during the 1987–1988 and 1988–1989 seasons are presented in Table 1.

Tests and analyses. Using various physiological and psychological tests, as well as high speed film analyses of skating techniques 237 different parameters were collected in our climate controlled laboratory and during National Speed Skating Championships. Considering the aim (and results) of this study, we will restrict our discussion of the methods to groups of parameters.

Technique analysis. Based on previous studies, a total of 164 technique parameters were selected and analyzed cinematographically with two 16-mm high speed cine cameras. The 1500-m distance was chosen for the analysis since this distance is often seen as the key distance in all-round speed skating.

Two synchronized high-speed cine cameras (Teledyne DBM55 Arcadia, CA and Bolex M16 Paillard, Santa Croix, Switzerland) were used, one to register the movements in the sagittal plane and one for the movements in the frontal plane. The cameras operated at nominal frame rates of 100 Hz and 50 Hz, respectively. Although no complete three-dimensional reconstruction was used, the angles measured from the sagittal films were corrected using the data of body rotation derived from the frontal film. The films were digitized manually using a motion analyzer (Summagraphics SPG-1212-RP, Austin, TX). Position data were low-pass filtered (Butterworth 4th order zero lag; cut off frequency: 20 Hz) and used to calculate the angles of the trunk (θ_1), upper leg (θ_2), lower leg (θ_3), and foot (θ_4) relative to the horizontal, the total joint angles, and angular velocities of hip (θ_h), knee (θ_k), and ankle (θ_a), and the translational velocity of the hip relative to the ankle, the push-off velocity (V_{ah}). From the frontal film the angle of the push-off leg with the vertical, the push-off angle (φ), was derived. A video camera (Panasonic SVHS Tokyo, Japan) was used to measure the stroke frequency on the straights and the curves. Earlier studies (3,19) provide more details about the cinematographic methods.

Using models for air- and ice-frictional losses based on wind tunnel experiments and ice friction measurements during actual skating (13,20), the external power produced by the athletes was estimated on the basis of speed, actual skating positions, and anthropometric measures. Work per stroke was calculated for both the curves and the straights by dividing the estimated external power by the stroke frequencies. Next to these absolute power and work measures, we also used them normalized to body mass or to lean body mass. From all angles, angular velocities, and translational velocities, maximal values were determined, as well as their values, at the onset of the push-off and at 100, 150, and 200 ms before the end of the push-off. The changes of angular positions during push-off were assessed, and from (angular) velocities the times were determined were these measures reached their maximal values, expressed in milliseconds before the end of the push-off (defined as the time at which the skate loses contact with the ice).

Physiological tests and anthropometric measures. For testing the physiological characteristics of the speed skaters, two tests, a 30-s sprint test and a 150-s supramaximal test, were performed on an electrically braked cycle ergometer (Mijnhardt, Bunnik, The Netherlands) during the competition period. The 30-s sprint test was a Wingate-type test that was performed in an all-out manner right from the start. The measured external power output was used to calculate peak power output and mean power output. Values for anaerobic work were calculated with the method described by de Koning et al. (21).

The warm-up for the 150-s test consisted of 3 min of cycling at 100 W and then 3 min of cycling at 180 W without a rest between the two sessions. The initial setting of the constant brake force on the flywheel of the ergometer is crucial for the outcome of both tests. Because all subjects had been tested previously, the individual brake settings were determined on the basis of previous performances as well as on load setting recommended in the literature (16). Mean power output was calculated from the instantaneous external power-time curves. Oxygen consumption ($\dot{V}O_2$) was measured for

30-s intervals during the warm-up and the actual test using an Oxycon-4 (Mijnhardt) gas analyzer. The external power and $\dot{V}O_2$ measured during the warm-up were used to calculate values for efficiency. Efficiency was used to calculate maximal aerobic power output. During the tests the subjects were vocally encouraged and continuously informed about remaining time.

The following anthropometrical measurements were made on all subjects: body mass and body length; upper leg length and lower leg length; girths of the upper leg and lower leg; biacromial breadth, pelvis breadth, and chest girth at expiration and inspiration; and thicknesses of the triceps, biceps, subscapular, and suprailiac skinfolds. Measurements were made in triplicate, and the mean was used. From the four skinfold measurements, body fat percentage was estimated according to Durnin and Womersley (5), and lean body mass was calculated.

Psychological tests. Psychological tests were used to obtain measures for both personality traits as well as psychological state during the skating competitions. During the cycle ergometer sessions, the subjects were asked to complete questionnaires to measure competitive trait anxiety and aspects of personality. Directly following the skating competition (National Championships), the subjects completed a questionnaire that measured competitive trait anxiety. Since it appeared impossible for them to complete this questionnaire just before the race, they were asked to report in retrospect their feelings just before the start of the race. Previous studies show that reporting emotional feelings in retrospect appears to be fairly reliable and is unaffected by the quality of performance (1,12). Competitive trait anxiety was measured with the Dutch version of the Sport Competition Anxiety Test (2,23). Personality traits were measured using the Adolescent Temperament List (6), which contains subscales for Emotionality, Thrill and Adventure Seeking (Sensation Seeking), Social Extroversion, and Impulsiveness. The Dutch version of the Competitive State Anxiety Inventory (2,23) was used to measure competitive state anxiety. This test contained subscales to measure cognitive anxiety, somatic anxiety, and self-confidence. No previous studies in which these measures were used to distinguish elite speed skaters from skaters of lower performance level are known.

Treatment of data. A total of 164 parameters from the technique analysis, 64 parameters from the two ergometer tests and anthropometric measurements, and 9 parameters from the psychological tests were identified. The total of 237 parameters (a number of which are dependent) in comparison with the small number of subjects renders sophisticated statistical methods such as factor analysis or multiple regression analysis meaningless.

To find performance-influencing factors, we calculated the correlation coefficients between the identified technical, physiological, anthropometric, and psychological variables and speed skating performance on the different competition distances (males, 500, 1500, and 5000 m; females, 500, 1500, and 3000 m) and the total points. These calculations were done for the years 1987–1988 and 1988–1989 separately. A variable was considered meaningful for speed skating performance if in both years a level of significance of $P < 0.05$ was reached. The correlation coefficients calculated between the variables and the total points are the most important values for identifying performance-determining factors for allround speed skating.

RESULTS

Table 1 shows that the range in performance of the subjects in this study is relatively small. The range in performance expressed in points is about 7%.

Selected variables from the physiological tests and anthropometric measurements are given in Table 2, while selected technical parameters are shown in Table 3. The values of the different parameters are in the same range as the results obtained from elite speed skaters presented in the literature (3,4,8,11,14,19,21) In Tables 2 and 3 the correlation coefficients between the selected variables and performance expressed in points are given.

Correlation coefficients between 237 parameters and 4 performance variables were calculated, resulting in 948 correlation coefficient calculations for each year for both males and females. Thus, a total of 3792 coefficients were calculated. As shown in Table 4, only a few of these coefficients were significant. Four hundred combinations of a performance variable and a physiological, anthropometrical, or technical parameter were significant. Because of the chosen significance level of 5%, $3792 \cdot 0.05 = 190$ of these significant combinations may be meaningless because they would not be significant in other comparable populations of speed skaters. Not one significant correlation of a psychological parameter with performance was found.

In this study the criterion was formulated that a variable is meaningful for speed skating performance if in both years of the analysis a level of significance of $P < 0.05$ was reached. In only 15 cases a variable was significant in the first as well as in the second year for the males and females together. This means that less then 1% of the possible combinations between performance and parameter were meaningful. The meaningful technical variables were all related to the push-off angle φ (r = -0.65 to -0.70), the trunk angle θ_1 (r = 0.61–0.73) and the hip extension velocity (r = 0.60–0.78). For both males and females, a more horizontal upper body position during the push-off (a small trunk angle θ_1) was associated with better performance on the 5000- and 3000-m distances, respectively. From the 474 correlations between the variables and the total points, only one variable was meaningful in both males and females. For

TABLE 3. Technique variables (mean and SD) and their correlation coefficients with performance (total points) during the two successive years of the study (I: 1987-88 and II: 1988-89) for males and females.

Variable	Mean (SD) I	Range I	Mean (SD) II	Range II
Males				
Push-off angle (φ) at onset push-off (°)	29.5 (3.1)	−0.65*	29.2 (3.0)	−0.70*
Push-off angle (φ) at end push-off (°)	41.6 (3.8)	−0.54	40.7 (1.8)	−0.36
Mean trunk angle (θ_1) gliding phase (°)	21.2 (6.2)	0.36	18.4 (3.9)	0.74*
Mean upper leg angle (θ_2) gliding phase (°)	47.9 (4.5)	−0.05	40.8 (3.4)	0.28
Mean lower leg angle (θ_3) gliding phase (°)	70.8 (3.6)	−0.03	68.7 (2.6)	−0.66
Mean knee angle (θ_k) gliding phase (°)	118.6 (5.7)	−0.06	109.5 (4.6)	−0.16
Trunk angle (θ_1) at onset push-off (°)	19.1 (4.2)	0.68	17.6 (5.3)	0.60
Upper leg angle (θ_2) at onset push-off (°)	66.6 (9.6)	−0.05	60.3 (5.9)	−0.19
Lower leg angle (θ_3) at onset push-off (°)	64.4 (14.1)	0.10	64.7 (5.7)	−0.69*
Knee angle (θ_k) at onset push-off (°)	131.0 (7.0)	0.13	124.9 (6.5)	−0.78*
Max knee angular velocity (°/s)	480 (64)	0.31	577 (111)	0.19
Push off velocity (V_{ah}), ($m \cdot s^{-1}$)	0.92 (0.30)	−0.45	1.18 (0.31)	0.21
Stroke frequency straights (s^{-1})	1.42 (0.10)	−0.27	1.44 (0.06)	−0.04
Stroke frequency curves (s^{-1})	1.79 (0.12)	0.04	1.83 (0.09)	0.05
External power output (W)	404 (49)	−0.36	368 (21)	−0.24
External power output/bpm ($W \cdot kg^{-1}$)	5.15 (0.49)	−0.19	4.72 (0.26)	−0.15
Work per stroke (J)	285 (35)	−0.23	256 (21)	−0.16
Work per stroke/bpm ($J \cdot kg^{-1}$)	3.64 (0.38)	−0.04	3.28 (0.20)	−0.09
Females				
Push-off angle (φ) at onset push-off (°)	24.1 (4.4)	0.19	26.4 (3.1)	−0.10
Push-off angle (φ) at end push-off (°)	36.9 (5.4)	0.36	38.5 (3.5)	−0.00
Mean trunk angle (θ_1) gliding phase (°)	19.0 (6.8)	0.50	18.3 (4.4)	0.15
Mean upper leg angle (θ_2) gliding phase (°)	46.4 (4.7)	−0.16	43.5 (4.1)	−0.36
Mean lower leg angle (θ_3) gliding phase (°)	67.9 (4.6)	−0.16	70.0 (2.1)	0.34
Mean knee angle (θ_k) gliding phase (°)	114.3 (6.6)	−0.22	113.5 (3.5)	−0.22
Trunk angle (θ_1) at onset push-off (°)	17.3 (7.4)	0.76*	17.6 (4.9)	0.48
Upper leg angle (θ_2) at onset push-off (°)	60.0 (7.8)	0.29	61.6 (6.2)	−0.49
Lower leg angle (θ_3) at onset push-off (°)	66.2 (14.1)	−0.16	66.4 (6.8)	0.54
Knee angle (θ_k) at onset push-off (°)	127.2 (13.0)	0.00	128.0 (6.4)	0.11
Max knee angular velocity (°/s)	587 (155)	−0.47	547 (128)	−0.54
Push off velocity (V_{ah}) ($m \cdot s^{-1}$)	1.21 (0.38)	0.48	1.00 (0.26)	−0.13
Stroke frequency straights (s^{-1})	1.35 (0.05)	0.46	1.45 (0.08)	0.30
Stroke frequency curves (s^{-1})	1.62 (0.09)	0.26	1.73 (0.10)	0.27
External power output (W)	242 (31)	−0.39	240 (30)	−0.40
External power output/bpm ($W \cdot kg^{-1}$)	4.04 (0.32)	−0.47	4.03 (0.30)	−0.48
Work per stroke (J)	180 (27)	−0.45	166 (26)	−0.42
Work per stroke/bpm ($J \cdot kg^{-1}$)	2.99 (0.31)	−0.53	2.79 (0.26)	−0.53

* Indicates significant correlation coefficients.

males, the meaningful variable was the push-off angle φ at the onset of the push-off. For females the hip extension velocity at the end of the gliding phase of the stroke was the only meaningful variable. The correlation coefficients show that a smaller hip extension velocity during the gliding phase and a larger push-off angle φ during the push-off results in better performance.

From the calculated correlation coefficients of anthropometrical and physiological variables, it seems that a large pelvis breadth (r = 0.71) and a low mechanical efficiency (r = 0.63–0.75) lead to better performance for males on the 500 m and 5000 m, respectively. These last "meaningful" results cannot be explained with the available literature on the physiology and technique of speed skating.

DISCUSSION

The major message of this study appears to be related to the absence of significant correlation coefficients with parameters that seemed to be so self-evident from previous work. The results are a strong affirmation of the results obtained in the biomechanical analyses of the middle and long distance speed skating events during the 1988 Olympics in Calgary (3). Boer and Nilsen's (33) results do not show a consistent picture of the technique of elite speed skaters either (with the exception of the push-off angle φ). The results of the present study show that this is true for physiological, anthropometric, and psychological measures as well.

Of course one might argue that this is the result of the choice of our subjects: the more homogeneous the group the lower the correlation coefficients. Table 4 shows that the highest number of significant correlation coefficients were found with performances in the 3000- and 5000-m races for the females and males, respectively. This can be explained by the larger range and standard deviation in performance on these longer distances (see Table 1) because among subjects of equal performance level one will, by definition, not show any significant correlation. A range of about 7% in performance seems too small to obtain a considerable amount of meaningful performance-determining parameters. So one might dispute the significance of studies with subjects with a relatively homogeneous level of performance.

TABLE 2. Physiological variables (mean and SD) and their correlation coefficients with performance (total points) during the two successive years of the study (I: 1987-88 and II: 1988-89) for males and females.

Variable	Mean (SD) I	Range I	Mean (SD) II	Range II
Males				
Body length (m)	1.84 (0.05)	−0.05	1.85 (0.04)	0.25
Body mass (kg)	78.3 (5.3)	−0.34	78.1 (5.6)	−0.11
Body fat (%)	10.8 (1.6)	−0.24	10.8 (1.1)	0.50
Lean body mass (kg)	69.8 (4.7)	−0.29	69.6 (5.0)	−0.19
$\dot{V}O_2$peak 150 s l·min^{-1}	4.88 (0.46)	−0.46	4.53 (0.34)	−0.39
$\dot{V}O_2$peak/bpm 150 s (ml·kg^{-1}·min^{-1})	62 (4)	−0.37	58 (2)	−0.57
Mean power 150 s (W)	534 (45)	−0.29	525 (52)	−0.24
Mean power/bpm 150 s (W·kg^{-1})	6.82 (0.35)	−0.03	6.72 (0.33)	−0.33
Peak power 30 s (W)	1355 (114)	−0.28	1336 (117)	−0.17
Peak power/bpm 30 s (W·kg^{-1})	17.29 (0.66)	−0.05	17.10 (0.82)	−0.17
Mean power 30 s (W)	1020 (84)	−0.27	1012 (70)	−0.20
Mean power/bpm 30 s (W·kg^{-1})	13.00 (0.57)	−0.01	13.00 (0.48)	−0.17
Anaerobic capacity (kJ)	41.32 (5.6)	−0.55	42.23 (4.7)	−0.31
Anaerobic capacity/bpm (J·kg^{-1})	517 (51)	−0.46	539 (31)	−0.41
Maximal aerobic power (W)	388 (51)	−0.23	395 (48)	−0.21
Maximal aerobic power/bpm (W·kg^{-1})	4.86 (0.41)	−0.02	5.05 (0.38)	−0.18
Females				
Body length (m)	1.67 (0.08)	−0.27	1.67 (0.09)	−0.14
Body mass (kg)	60.0 (6.6)	−0.12	59.5 (5.7)	−0.15
Body fat (%)	21.6 (3.1)	0.41	21.3 (2.4)	0.37
Lean body mass (kg)	47.0 (4.4)	−0.29	46.9 (4.1)	−0.30
$\dot{V}O_2$peak 150 s (l·min^{-1})	3.25 (0.27)	−0.24	3.07 (0.20)	−0.23
$\dot{V}O_2$peak/bpm 150 s (ml·kg·min^{-1})	54 (4)	−0.12	52 (3)	−0.00
Mean power 150 s (W)	360 (36)	−0.04	356 (33)	−0.28
Mean power/bpm 150 s (W·kg^{-1})	6.02 (0.61)	0.04	6.00 (0.41)	−0.16
Peak power 30 s (W)	921 (100)	−0.30	868 (96)	−0.56
Peak power/bpm 30 s (W·kg^{-1})	15.40 (1.31)	−0.27	14.60 (1.28)	−0.56
Mean power 30 s (W)	691 (77)	−0.35	674 (69)	−0.66*
Mean power/bpm 30 s (W·kg^{-1})	11.55 (0.93)	−0.37	11.36 (0.93)	−0.62*
Anaerobic capacity (kJ)	26.65 (4.7)	−0.45	26.45 (3.4)	−0.53
Anaerobic capacity/bpm (J·kg^{-1})	449 (68)	−0.44	444 (52)	−0.45
Maximal aerobic power (W)	286 (35)	−0.19	271 (27)	−0.05
Maximal aerobic power/bpm (W·kg^{-1})	4.83 (0.53)	−0.04	4.56 (0.49)	0.11

* Indicates significant correlation coefficients.

TABLE 4. Number of significant ($P < 0.05$) correlation coefficients between the variables and performance during the two years of the study (I: 1987-88 and II: 1988-89).

Males	500 m	1500 m	5000 m	Points	Total
Physiological variables I	1	11	14	13	
Technical variables I	5	2	5	3	
Total I	6	13	19	16	54
Physiological variables II	31	37	61	50	
Technical variables II	2	0	2	1	
Total II	33	37	63	51	184
Total I and II					238
Females	**500 m**	**1500 m**	**3000 m**	**Points**	**Total**
Physiological variables I	15	15	17	15	
Technical variables I	1	0	0	0	
Total I	16	15	17	15	63
Physiological variables II	5	11	58	9	
Technical variables II	7	4	2	3	
Total II	12	15	60	12	99
Total I and II					162

However, coaches of national teams often appeal to sport scientists for advice or assistance to optimize the performances of their athletes. The results of this study show that we can hardly help them with the tests and descriptive types of analyses used [see also (9)].

The results of the extensive and time consuming analyses and calculations performed in this study justify only advising coaches of young skaters to improve the trunk position and push-off angle φ.

Together with previous observations that our (and other) physiological tests largely fail to detect changes in physiological measures during a season despite large changes in volume, nature, and intensity of the training (7,9,17), the results of this study show that the profits of these types of scientific investments are extremely low.

Differences in performance among members of national teams are most likely due to many factors that are more difficult to distinguish at higher performance levels. Table 1, for example, shows that the range in time is only about 7%. If this is explained by, for example, 50 possible differences covering a large variety of physical, technical, and psychological factors, researchers in sport science (or human movement science in general) will have to develop more reliable models, methods, and theories to contribute significantly to knowledge that is useful to top athletes and their coaches. This problem is amplified by the small number of top speed skaters to study. Other studies show that these conclusions are most likely true for other sports as well, although there is still a need to search for important requisites for many sports in which, for example, even the basic mechanics are not yet understood.

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